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Effect of the number of two-wheeled containers at a gathering point on the energetic workload and work efficiency in refuse collecting

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Abstract

The effect of the number of two-wheeled containers at a gathering point on the energetic workload and the work efficiency in refuse collecting was studied in order to design an optimal gathering point for two-wheeled containers. Three sizes of gathering points were investigated, i.e. with 2, 16 and 32 two-wheeled containers at a gathering point. The collecting of two-wheeled containers was simulated in a test circuit. The energetic workload was quantified by the parameters oxygen uptake ($\mathrm{l\,min^{-1}}$), heart rate ($\mathrm{beats\,min^{-1}}$) and perceived exertion. The work efficiency was quantified as the time it took to collect 32 two-wheeled containers per time period. The maximum acceptable amount of two-wheeled containers collected during an 8-h working day was estimated using the energetic criterion of a maximum oxygen uptake of 30% VO_{2max}. The size of the gathering point had no effect on the oxygen uptake, heart rate or perceived exertion. However, the number of two-wheeled containers per collecting period (work efficiency) and the maximum acceptable amount during an 8-h working day were higher in the conditions with 16 and 32 two-wheeled containers at a gathering point compared to the condition with the 2 two-wheeled containers at a gathering point.

Keywords: Pushing/pulling; Energetic workload; Work efficiency

1. Introduction

Refuse collecting is a physically demanding job, which is associated with a high prevalence rate of musculoskeletal disorders and a high sickness absence rate (Frings-Dresen et al., 1995a; Poulsen et al., 1995). At present, in The Netherlands most refuse is collected by means of two-wheeled containers. Before the refuse collectors collect the two-wheeled containers, the citizens place the two-wheeled containers in more or less random positions on the street. The number of two-wheeled containers at a gathering point, i.e. the place on the street where citizens place their two-wheeled containers, ranges between 1 and more than 30 two-wheeled containers. In the urban areas the distance between small gathering points of 3–4 two-wheeled containers is normally covered by walking, while the distance between large gathering points of more than 6 two-wheeled containers is normally covered while standing on the foot-board on the back of the refuse truck. One of the possible work improvements is to change the number of two-wheeled containers at a gathering point. Before implementing such a work improvement, it is imperative to establish its effect on the workload of the refuse collectors and on the work efficiency. In general, in the case of small gathering points short periods of pushing and pulling are alternated with periods of walking, while in the case of large gathering points longer periods of pushing and pulling are alternated with short periods of standing. Most studies on the

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effect of alternating tasks or work-rest schedules on the workload only reported the effects of tasks that lasted several minutes and did not pay attention to short-lasting activities within these tasks (Rohmert, 1973; Deivanayagam and Ayoub, 1979; Price, 1990). Therefore, existing guidelines on alternating between tasks and work-rest schedules were not applicable for this specific situation.

A guideline that is of importance, is the energetic workload guideline for refuse collectors (Frings-Dresen et al., 1995b). This guideline specifies, for instance, the maximum acceptable amount of collecting hours, the maximum acceptable amount of refuse ($\times 10^3$ kg) and the maximum acceptable number of two-wheeled containers collected for male refuse collectors of three age groups (<30, 30–39, >39) for an 8 h working day. The objective of this study was to establish the effect of the number of two-wheeled containers at a gathering point on the energetic workload and the work efficiency in order to design an optimal gathering point for two-wheeled containers.

2. Method

2.1. Participants

Six males, from each of the three age groups of the energetic workload guideline for refuse collectors (Frings-Dresen et al., 1995b), voluntarily participated. The participants were no refuse collectors. Age, body height and body weight of the participants are presented in Table 1.

2.2. Experimental design

In deliberation with experts from waste management companies, we have chosen to study three sizes of gathering points because these sizes represent the range that is seen in daily practice and can be implemented in a large part of The Netherlands. The three sizes were 2, 16 and 32 two-wheeled containers at a gathering point. Two refuse collectors normally collect refuse at a time. This implicates for this study that each participant collected per gathering point 1, 8 and 16 two-wheeled containers, respectively. In every condition, a total of 96 two-wheeled containers was collected. The six possible orders of the three loading conditions were systematically varied across the six participants of each age category. After every loading condition, the participant rested for 20 min.

The task collecting of two-wheeled containers was simulated as well as possible. A test circuit was designed on which a full (content: 240 l, weight of refuse 22 kg) and an empty two-wheeled container (content: 240 l, no refuse) had to be pushed and pulled (Fig. 1). The working technique, the work tempo and the weight of the two-wheeled container were based on observations and measurements made during a field study (Frings-Dresen et al., 1995a). The different activities of the test circuit are presented in Table 2. The surface of the test circuit consisted of a brick paved road. In order to create an optimal gathering point, the two-wheeled containers in all three conditions were easy to get. It was as if the two-wheeled containers were placed in two straight lines behind each other with their handles placed to the street. Moreover, there were no kerbs or other obstacles. The activities of the test circuit were performed in the following order. First, the full two-wheeled container was tilted and pulled with one hand from point A to B.

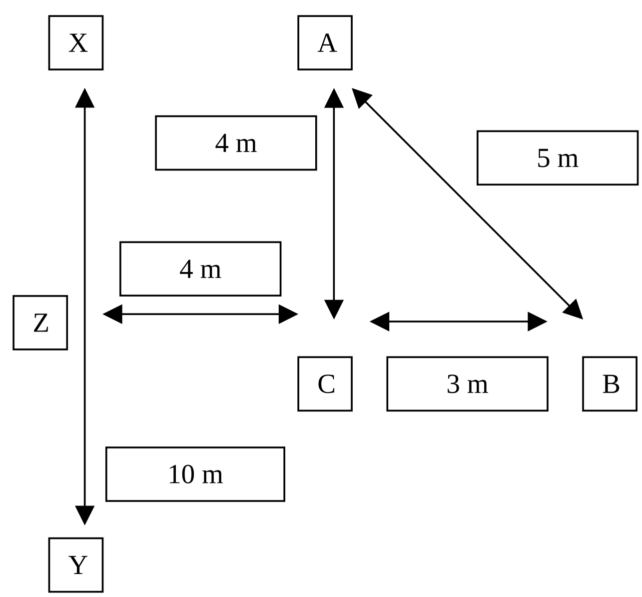

Fig. 1. Schematic representation of the test circuit for pushing and pulling of a full and empty two-wheeled container for the three sizes of gathering points.

Table 1
Mean and standard deviation (s.d.) of age, body height and body weight of the male participants per age group

Age group (year)	Number (n)	Age (years) mean (s.d.)	Height (cm) mean (s.d.)	Weight (kg) mean (s.d.)
<30	6	26 (2)	184 (4)	76 (7)
30–39	6	33 (1)	187 (4)	75 (4)
>39	6	47 (5)	181 (7)	89 (13)

Table 2
The activities (including distance and estimated time) of the test circuit

Activity	Distance (m)	Estimated time (s)
Pulling of a loaded two-wheeled container with one hand	5	4
Pushing of a loaded two-wheeled container with two hands	3	3
Standing	0	5
Pulling of an empty two-wheeled container with one hand	4	3
Grabbing an empty two-wheeled container	0	3
Walking to gathering point (2 two-wheeled containers per gathering point)	20	15
Walking between gathering point and refuse truck (16 and 32 two-wheeled containers per gathering point)	12	9
Standing on foot-board (16 two-wheeled containers per gathering point)	0	19
Standing on foot-board (32 two-wheeled containers per gathering point)	0	38

At point B the two-wheeled container was turned and pushed with two hands to point C. At point C the two-wheeled container was tilted forward and placed in the upright position. The participant waited for 5 s (the estimated time it takes to empty a two-wheeled container mechanically). Then, the empty two-wheeled container was tilted and pulled with one hand to point A, where the empty two-wheeled container was turned 180°, tilted forward, and placed in the upright position. In the condition with 2 two-wheeled containers per gathering point, the participant then walked over a distance of 20 m (the estimated distance between two gathering points in the work situation). In Fig. 1 this is two times the distance between points X and Y. After that, the activities were performed in reverse order. The empty two-wheeled container was moved from C to B. Again the participant waited for 5 s. Then, the full two-wheeled container was moved from C via B to A. In the conditions with the 16 and 32 two-wheeled containers, the participant did not walk over a distance of 20 m, but directly continued with pulling the empty two-wheeled container back from point A to C. After having collected 8 and 16 two-wheeled containers, respectively, the participant walked 12 m from point A via B to point Z. Over there the participant stood still during 19 and 38 s, respectively. This is the time it takes for a refuse truck to drive a distance of 160 and 320 m, respectively, at 30 km h^{-1}, which is the maximum automatically enforced speed when a refuse collector is standing on the foot-board on the back of the truck. Due to this limited speed and the stringent guidelines on the design of the foot-board and the handles on the back of the truck, the refuse collectors are standing upright and do not have to support a large part of their body weight with their arms. Therefore, it is expected that standing still resembles standing on the foot-board of the truck quite well. Then, the participant walked the same way back to start collecting at the next gathering point. To ensure that every participant worked at the same speed in every condition, an experimenter checked the time of the different activities during the test circuit using a chronometer. When necessary, the participants were urged to speed up or slow down.

2.3. Energetic workload and work efficiency

The energetic workload was quantified by the oxygen uptake (l min^{-1}), heart rate (beats min^{-1}) and perceived exertion. Oxygen uptake and heart rate were measured breath by breath using a portable analyser (Cosmed K4b^2, Cosmed Italy) (Hausswirth et al., 1997). The perceived exertion was assessed using a visual analog scale (Zijlstra, 1993). The oxygen uptake and heart rate during the handling of the final 32 two-wheeled containers were used for analysis. After having collected all 96 two-wheeled containers and before pausing for 20 min, the participants rated the perceived exertion. To prevent possible bias due to a training effect, the work efficiency was quantified as the time it took to collect the final 32 two-wheeled containers in the three conditions.

To estimate the maximum acceptable time of refuse collecting and the maximum acceptable number of two-wheeled containers per 8-h working day for the three gathering points, the Eqs. (1) and (2) from the study of Frings-Dresen et al. (1995b) were used:

$$C_{\text{ollecting minutes}} {*} VO_{2\text{collecting}} + N_{\text{ot collecting minutes}} {*} VO_{2\text{not collecting}} = 480 * 30\% VO_{2\max}, \quad (1)$$

$$C_{\text{ollecting minutes}} + N_{\text{ot collecting minutes}} = 480. \quad (2)$$

The oxygen uptake during collecting ($VO_{2\text{collecting}}$) was measured in this study as described above. The oxygen uptake during the 'not collecting time' (i.e. performing other tasks than collecting, such as driving, pausing or refuelling the truck) was taken from the study by Frings-Dresen et al. (1995b) ($VO_{2\text{not collecting}} = 0.38\ \text{l min}^{-1}$). The $VO_{2\max}$ for the P_{10} of every age category was also based on that study ($VO_{2\max\ <30\ \text{year}} = 3.1\ \text{l min}^{-1}$, $VO_{2\max\ 30-39\ \text{year}} = 2.6\ \text{l min}^{-1}$ and $VO_{2\max\ >39\ \text{year}} = 2.1\ \text{l min}^{-1}$) (Frings-Dresen et al., 1995b). After calculating the maximum acceptable collecting time, the maximum acceptable number of two-wheeled containers were calculated by taking into account the average time it took to collect 1 two-wheeled container in each of the three conditions.

2.4. Data analyses

The effect of the size of the gathering points on the oxygen uptake, heart rate, perceived exertion and the collecting time per age group was tested using a within subjects ANOVA with multiple dependent measures analysis of variance. A p-value smaller than 0.05 was considered statistically significant.

3. Results

The size of the gathering points had no effect on the oxygen uptake ($\mathrm{l\,min^{-1}}$) (Table 3). The results of one participant of the age group 30–39 were left out of the analyses because his values were more than two times the standard deviation smaller than the average value. The oxygen uptake for the three age groups varied between 1.25 and 1.49 $\mathrm{l\,min^{-1}}$, which was not significant.

The size of the gathering points had no effect on the heart rate ($\mathrm{beats\,min^{-1}}$) (Table 4). The heart rate for the three age groups varied between 99 and 110 $\mathrm{beats\,min^{-1}}$. No significant differences were found, neither between the gathering points nor between the age groups.

The size of the gathering points and the age groups had no significant effect on the perceived exertion (Table 5). The collecting of two-wheeled containers was qualified by the participants between ‘somewhat’ and ‘rather’ effortful.

The size of the gathering point had a significant effect on the collecting time (Table 6). The collecting of two-wheeled containers took a longer time on a gathering point with 2 two-wheeled containers than on a gathering point with 16 or 32 two-wheeled containers. The latter two conditions did not differ significantly. There was no significant effect between age groups.

In Table 7 the results are presented of the effect of the size of the gathering point on the maximum acceptable collecting time and the corresponding maximum accep-

Table 3
Mean and standard deviation (s.d.) of the oxygen uptake ($\mathrm{l\,min^{-1}}$) per age group for the three sizes of gathering points

Age	Oxygen uptake ($\mathrm{l\,min^{-1}}$)						Significance
	2 Containers		16 Containers		32 Containers		
	Mean	s.d.	Mean	s.d.	Mean	s.d.	
<30	1.38	0.21	1.41	0.22	1.31	0.24	—
30–39	1.36	0.24	1.25	0.18	1.37	0.24	—
>39	1.49	0.34	1.33	0.22	1.36	0.28	—

Table 4
Mean and standard deviation (s.d.) of the heart rate ($\mathrm{beats\,min^{-1}}$) per age group for the three sizes of gathering points

Age	Heart rate ($\mathrm{beats\,min^{-1}}$)						Significance
	2 Containers		16 Containers		32 Containers		
	Mean	s.d.	Mean	s.d.	Mean	s.d.	
<30	103	13	104	12	106	16	—
30–39	99	10	100	14	99	13	—
>39	110	9	107	15	109	14	—

Table 5
Mean and standard deviation (s.d.) of the perceived exertion per age group for the three sizes of gathering points

Age	Perceived exertion						Significance
	2 Containers		16 Containers		32 Containers		
	Mean	s.d.	Mean	s.d.	Mean	s.d.	
<30	47	17	43	14	46	15	–
30–39	54	14	50	18	56	18	–
>39	37	22	41	17	38	24	–

Table 6
Mean and standard deviation (s.d.) of the time (minutes) it took to collect 32 two-wheeled containers per age group for the three sizes of gathering points

Age	Time to collect 32 two-wheeled containers (min)						Significance
	2 Containers		16 Containers		32 Containers		
	Mean	s.d.	Mean	s.d.	Mean	s.d.	
<30	18.3	1.0	12.3	0.8	12.1	1.3	2 > 16 and 32
30–39	17.0	0.9	12.6	1.0	12.2	1.3	2 > 16 and 32
>39	18.5	1.8	12.8	0.9	12.0	0.8	2 > 16 and 32

Table 7
Effect of the size of the gathering points on the maximum acceptable collecting time (hours) and maximum acceptable number of two-wheeled containers collected (#) per 8-h working day

Age		2 Containers	16 Containers	32 Containers
<30	Hours	4.5	4.5	4.5
	#	481	691	709
30–39	Hours	3.3	3.3	3.3
	#	350	502	516
>39	Hours	2.0	2.0	2.0
	#	218	314	322

table number of two-wheeled containers per 8-h working day. Because the oxygen uptake did not differ between the three different conditions, the mean oxygen uptake averaged over the three conditions and the three age groups was taken (1.36 l min^{-1}). Therefore, the maximum acceptable collecting time did not differ between the three conditions. However, as seen in Table 6, the work efficiency did differ. In the condition with 2 two-wheeled containers per gathering point, the time per two-wheeled container was 0.56 min, with 16 two-wheeled containers per gathering point 0.39 min and with 32 two-wheeled containers per gathering point 0.38 min. Therefore, the maximum acceptable number of two-wheeled containers collected per day was higher in the condition with the gathering points consisting of 16 and 32 two-wheeled containers than in the condition with 2 two-wheeled containers.

4. Discussion

4.1. Experiment

The results of the present study indicate that size of the gathering point has no effect on the oxygen uptake, heart rate or perceived exertion. However, the number of two-wheeled container collected per period (work efficiency) is higher in the conditions with 16 and 32 two-wheeled containers at a gathering point than in the condition with the 2 two-wheeled containers at a gathering point. Before these results are generalised to the daily practice, one of the first questions to be answered is whether the workload in the test circuit resembled the workload in real life. The estimated oxygen uptake and measured heart rate in a field study among refuse collectors of two-wheeled containers were 1.36 l min^{-1} and 115 beats min^{-1} (Frings-Dresen et al., 1995a). The measured oxygen uptake and heart rate in this study, averaged over the three conditions and the three ages groups, were 1.36 l min^{-1} and 104 beats min^{-1}. The refuse collectors from the field study rated their perceived exertion as 39 ("somewhat effortful") (Stassen et al., 1993). The averaged perceived exertion in this study was 45 ("somewhat to rather effortful"). On basis of these parameters it is considered that the workload during the test circuit resembled the workload in daily practice reasonably well. This only holds, however, if there are no differences in working technique between expert and novice refuse collectors. A better working technique may results in a reduction of the energetic workload while the production output (in this case the number of two-wheeled containers collected per time period) remains the same (Kilbom, 1997). A study on the handling of boxes indicated that strategies used by experts permit better control of the load and a more efficient use of box momentum (Authier et al., 1996). Gagnon et al. (1996) found that expert handlers of boxes choose a strategy that was more efficient in terms of mechanical energy expenditure. In contrast, in a field study on refuse collectors of bags, Cloutier (1994) could not find differences in working technique between younger and older refuse collectors. This might, however, be due to the use of visual observation, which might not be sensitive enough to establish subtle differences. When differences in working technique between novices and experts do exist for pushing and pulling of two-wheeled containers, expert refuse collectors would probably use less oxygen and rate their exertion lower than the participants in the present study. In that case, the workload during the test circuit was lower than in daily practice. Whether or not the workload in the test circuit resembled the workload in daily practice, a difference in working technique probably has no effect on the results because the experiment was performed with a repeated measures design and possible differences in efficiency are probably the same in the three conditions.

To increase the face validity of the study for an 8-h working day, each participant had to collect two-wheeled containers in each condition for more than 30 min. Therefore, in each condition 96 two-wheeled containers were collected with a total of 288 for the whole experiment. For the participants of the age group >39 year, this is even more than is allowed for an 8-h working day according to the guideline of Frings-Dresen et al. (1995b).

The two-wheeled container was filled with a mass of 22 kg and weighed about 40 kg. In daily practice the weight of the filling of a two-wheeled container varies between less than a few kg and more than 60 kg. Sanchez et al. (1979) found that for pushing and pulling of loads from 6 to 24 kg the oxygen and cardiac cost increased linearly with the load. If this linear relation also holds true for the loads used in daily practice, there is no effect to be expected of a variation in mass on the level of the energetic workload. When this linearity does not exist for loads above 24 kg, the increase in oxygen uptake would have been the same for all three conditions. Therefore, this would not have affected the results in terms of energetic workload. In daily practice it seldom occurs that two-wheeled containers with over 60 kg are loaded. In that case, relatively high peak compression forces are alternated with less physically demanding activities (Van Dieën and Oude Vrielink, 1994). Therefore, it is expected that the size of the gathering point does not affect the biomechanical load.

4.2. Energetic workload and work efficiency

An important difference between the three conditions was that the distance between gathering points in the condition with 2 two-wheeled containers was covered by walking instead of standing on the foot-board of the back of the truck. The assumption that the time walking can be classified as recovery time compared to the time pushing and pulling of a two-wheeled container seemed not to be valid in this situation. Two possible explanations can be given. First, intensity of walking might have been comparable to the intensity of pushing and pulling a two-wheeled container. The oxygen uptake while walking at a speed of $5\,\mathrm{km\,h^{-1}}$ is about $0.9\,\mathrm{l\,min^{-1}}$ and for a speed of $7\,\mathrm{km\,h^{-1}}$, this is about $1.5\,\mathrm{l\,min^{-1}}$ (Åstrand and Rodahl, 1986). Although the participants were asked to walk with a speed of about $5\,\mathrm{km\,h^{-1}}$, it is possible that they walked slightly faster. Second, the time of walking might have been too short in comparison with the time pushing and pulling to effectuate recovery.

In this study only the energetic workload was quantified. No information was available on the biomechanical workload during the test. Van Dieën and Oude Vrielink (1994) showed that frequent short periods of less physically demanding activities are to be preferred above few long periods for the biomechanical load of the back while performing the same work. When applying the energy model of Van Dieën and Toussaint (1997) using information based on the (peak) compression forces during pushing and pulling of two-wheeled containers from the studies of De Looze et al. (1995) and Schibye et al. (1997) no differences were found between the three conditions. This is probably because of the relatively small (peak) compression forces and the logarithmic effect of the number of loading cycles. In all three conditions, it is estimated that 6% of the population was at risk. This same model (Van Dieën and Toussaint, 1997) was used to estimate the effect on the biomechanical load for the maximum acceptable number of two-wheeled containers for an 8-h working day. Despite the fact that more two-wheeled containers were collected in the case of a larger gathering point, no differences were found between the three conditions. In all three conditions about 7% of the population was at risk. Therefore, the energetic workload criteria seemed to be relevant.

4.3. Relevance for daily practice

What is the relevance of this study for daily practice? Although the energetic workload is reasonably comparable with a real collecting situation, the results from this experiment cannot be translated directly to the daily practice of refuse collectors. A few conditions have to be met. First, the two-wheeled containers in this study were easy to get hold of. In daily practice the two-wheeled containers often stand criss-cross in a heap on the sidewalk. The refuse collector often has to move more than 1 two-wheeled container before getting a new one. This means that two-wheeled containers have to be placed in two straight lines behind each other with their handles placed to the street. Second, no kerbs and other obstacles had to be overcome in this study. Third, the pushing and pulling distance did not vary between the two-wheeled containers. This means that the distance between the two-wheeled container and the (driving) refuse truck has to be of a constant length. Fourth, the introduction of a gathering point takes a lot of (parking) space in the streets. Because there were no significant differences between the conditions of 16 and 32 two-wheeled containers, a gathering point of 16 two-wheeled containers seems most preferable on basis of this study.

Citizens play an important role in creating an optimal gathering point for 16 two-wheeled containers. In general, once a week they have to transport their two-wheeled container over a larger distance and have to place their two-wheeled container in two lines of 8 two-wheeled containers with the handles towards the street. Most two-wheeled containers are already placed with the handles towards the street. In The Netherlands, every household receives information about where, when and how the refuse should be placed on the street. When the two-wheeled container is improperly placed on the street, the refuse collectors attach yellow ('warning: next time two-wheeled container will not be emptied') and red cards ('penalty: two-wheeled container is not emptied') to the two-wheeled container. Ultimately, the correct behaviour is enforced by imposing fines.

Finally, once these gathering points are implemented further study is needed to evaluate whether the workload in daily practice is comparable with the estimated workload in the present study and whether the estimated acceptable increase in number of two-wheeled containers is still in accordance with the Dutch energetic workload guideline for refuse collectors (Frings-Dresen et al., 1995b).

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